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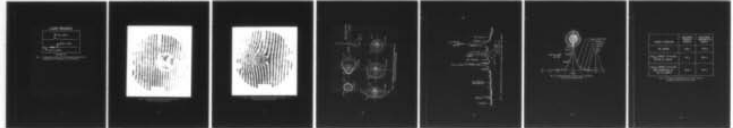
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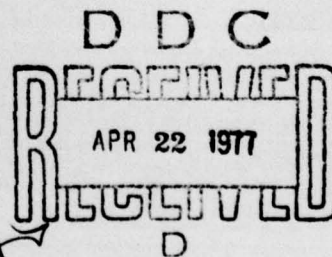
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NRL Memorandum Report 3457

# Production of Large Warm Plasmas by Staged Laser Heating of Solid Targets

R. E. PECHACEK AND J. R. GREIG

*Experimental Plasma Physics  
Plasma Physics Division*

February 1977



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A 1000 Joule CO <sub>2</sub> laser pulse, focussed on a slowly expanding ( $\dot{r} = 2 \times 10^5$ cm/sec) gas cloud in a vacuum chamber, ionizes the gas by laser spark breakdown, and then heats it by inverse bremsstrahlung absorption. The resulting plasma contains about $10^{19}$ ions at a temperature of approximately 50 eV. The gas cloud is created by irradiating a solid plastic target with a 10 J prepulse and a 100 J main pulse from a Nd/glass laser. Two advantages of these two laser plasma production systems over irradiating a solid target directly with the CO <sub>2</sub> laser are (1) the density of the target		

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$$(T_{sub 0}) \left( (r_{sub 0})/r \right)^{3/2}$$

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## 20. Abstract (Continued)

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gas cloud is an adjustable parameter that can be used to vary the plasma temperature and total number of particles, and (2) since the temperature of an expanding plasma decreases as  $T(r) = T_0 (r_0/r)^2$  and since  $r_0$  is a factor of ten larger for a gas than a solid, the temperature at large  $r$  of a plasma that originated as a cloud is a factor of  $10^2$  higher than one that was heated at the radius of a solid, provided of course, that the initial temperature and particle number are the same in both cases.

100

$r_{sub 0}$



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## PRODUCTION OF LARGE WARM PLASMAS BY STAGED LASER HEATING OF SOLID TARGETS

### I. INTRODUCTION:

This paper describes the initial results of an experiment that was designed to produce a large, warm plasma that could be used as an initial plasma to be heated in a higher temperature containment device, or simply used as a source of clean, high- $\beta$  plasma to be used in basic plasma physics studies, such as the study of the plasma losses from magnetic cusps.

This paper is organized in the following way: First, we shall describe the method of plasma production; then the results of our diagnostic effort and the plasma properties, and finally we will try to correlate the plasma properties with the results of our earlier study of the gas clouds produced by a Nd-Gl laser pulse.

### II. METHOD OF PLASMA PRODUCTION:

Figure 1 illustrates the method of plasma production. The tip of a 0.5 X 0.5mm polyethylene filament is irradiated by a tailored pulse from a 100 joule Nd-Gl laser. The laser beam is focussed and produces an intensity of about  $2.5 \times 10^{11}$  watts/cm<sup>2</sup>. The initially created plasma, of  $4 \times 10^{17}$  particles, rapidly blows off, leaving a cloud of  $(CH_2)_n$  vapor and particulate matter that expands slowly, at a rate of about  $10^5$  cm/sec. This cloud is allowed to expand for several microseconds, until its density is of the order of  $10^{19}$  cm<sup>-3</sup> and then it is irradiated by a focussed CO<sub>2</sub> laser pulse with an energy of about 1000J and a peak intensity of  $2 \times 10^9$  watts/cm<sup>2</sup>. This second laser pulse essentially produces a laser spark, and completely ionizes the cloud.

Note: Manuscript submitted February 4, 1977.

Figure 2 is a schematic diagram of the top view of the experiment. The laser beams are focussed by 1.0 meter focal length lenses. The polyethylene filament lies perpendicular to the plane of the figure. The base pressure in the vacuum chamber is about  $3 \times 10^{-6}$  T. The calorimeter and photon drag detectors measure the  $\text{CO}_2$  laser energy transmitted through the target. After the plasma is created, it is observed holographically and spectrographically. The light path of the holographic system is in the plane of the figure, through two five inch diameter windows, and not quite perpendicular to either laser beam.

Figure 3 shows the timing sequence of the lasers and also their pulse shapes. The Nd-Gl laser pulse length is about 40nsec and it is preceded by a pre-pulse, which is necessary if the cloud is to contain more vapor and less particulate matter. The  $\text{CO}_2$  laser signal is ordinary. It contains about 30% of its energy in a 70nsec peak and the remainder in a tail that extends to about 2 $\mu$ sec. The energy in the pulse is between 600 and 700 Joules and the peak power is about 2GW. The  $\text{CO}_2$  laser is followed by a 20nsec wide, ruby laser pulse that holographically records the plasma properties. In the experiments reported here, the interval between the Nd-Gl and  $\text{CO}_2$  laser was kept relatively constant, and the plasma evolution was studied by varying the time of the holographic record.

### III. EXPERIMENTAL RESULTS

Figure 4 is a holographic interferogram taken 300 nsec after the  $\text{CO}_2$  laser peak. As with an interferogram made with a Mach-Zehnder interferometer, fringe shift is proportional to index of refraction variations and, therefore, plasma density variations. The  $\text{CO}_2$  laser is incident from the right, in the direction of the arrowhead, and the

Nd-Gl from the left. The three squares on the left are each 1 cm square, and allow the interferogram to be scaled. Notice the sharp front, that it is expanding toward the CO<sub>2</sub> laser, and that at its maximum it has traveled over 3 cm in 300nsec. At the time of this picture, less than half of the CO<sub>2</sub> laser energy has been emitted.

Figure 5 is an interferogram taken 1300 nanoseconds after the peak of the CO<sub>2</sub> laser, after nearly all of the laser energy has been emitted. Notice that the plasma expanding toward the CO<sub>2</sub> laser has expanded out of the picture, and that a second front, not nearly as sharp as the first, is expanding in the opposite direction. We intend to study the relation between this second front and the CO<sub>2</sub> laser tail in experiments in which the laser tail has been eliminated.

Assuming cylindrical symmetry, these interferograms can be Abel inverted and the plasma density as a function of position can be calculated.

Figure 6 is a set of isodensity contours, calculated from interferograms taken at various intervals after the peak of the CO<sub>2</sub> laser pulse. The curves refer to electron densities of  $10^{16}$  cm<sup>-3</sup>,  $2 \times 10^{16}$ ,  $10^{17}$ ,  $2 \times 10^{17}$  and  $10^{18}$  cm<sup>-3</sup>. Integration over the plasma volume results in a total number of electrons of about  $2 \times 10^{19}$ . The upper right hand diagram in this figure illustrates the initial neutral density.

Figure 7 is the spectrum of light in the visible and u-v range that is emitted by the plasma. The optic axis of the spectrograph crosses the CO<sub>2</sub> laser axis about 5mm in front of the polyethylene target. The presence of the CIV lines indicate that the plasma ions are mostly H<sup>+</sup> and C<sup>+++</sup>. Also the half width of the H <sub>$\beta$</sub>  line, 80Å, which corresponds to an electron density of  $2 \times 10^{17}$  cm<sup>-3</sup>, is consistent with the densities computed from the interferograms.

#### IV. COMPARISON WITH EARLIER WORK

Figure 8 is a plot of the neutral density distribution at the time the CO<sub>2</sub> laser is fired. This curve is the result of our previous study, to be published in JAP<sup>2</sup>, which showed that the gas cloud density from a Nd-Gl laser evaporated target falls as  $e^{-r/r_0}$  where  $r_0$  increases linearly with time. The constants in the expression are consistent with a fully ionized plasma of  $2 \times 10^{19}$  electrons,  $.6 \times 10^{19}$  H<sup>+</sup> and  $.3 \times 10^{19}$  C<sup>+++</sup>. Eighty percent of the CO<sub>2</sub> laser energy falls within a radius of 0.5 cm, which contains less than 30% of the neutrals. The laser pulse heats the cloud center, which in turn ionizes the exterior atoms by u-v and x-radiation. The hot central cloud then expands, sweeping the cooler background plasma with itself. The values of the coulomb mean free path of the 50eV expanding plasma through the background plasma show that to distances of about 3 cm, a narrow front should be expected. We believe that the initial front that expands toward the CO<sub>2</sub> laser is generated by the initial spike of the laser signal and the second is due to the remainder and bulk, of the signal.

Finally, the last figure (9) is shown for any disbelievers who doubt the necessity of the Nd-Gl laser to this experiment. This figure shows that, without the Nd-Gl laser pulse, essentially the entire CO<sub>2</sub> laser pulse is transmitted through the target area while, with the Nd-Gl pulse, only about 20% is transmitted.

In conclusion let us mention our plans for this work. We want to

- 1) Do a study in which the Nd-Gl laser -CO<sub>2</sub> laser interval is varied.
- 2) Study the effect of varying the CO<sub>2</sub> laser pulse shape.
- 3) Apply a cusp magnetic field to the plasma.

4) Measure temperature using laser scattering techniques.

5) Use a deuterium target.

ACKNOWLEDGEMENTS:

We want to acknowledge many helpful discussion with Drs. Alan DeSilva and David Koopman and also the continued interest and encouragement of Dr. A. E. Robson.

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2. J. R. Greig and R. E. Pechacek, The Disintegration and Vaporization of Plastic Targets Irradiated by High Power Laser Pulses, to be published in Journal of Applied Physics.

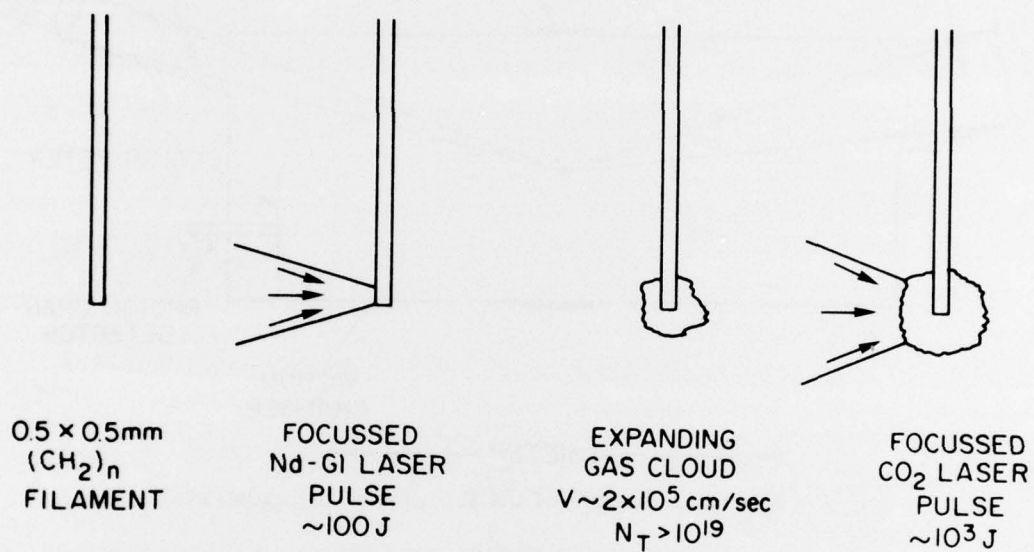


Fig. 1 — The plasma is produced by irradiation of a polyethylene filament by a Nd/glass laser pulse, followed by a CO<sub>2</sub> laser pulse

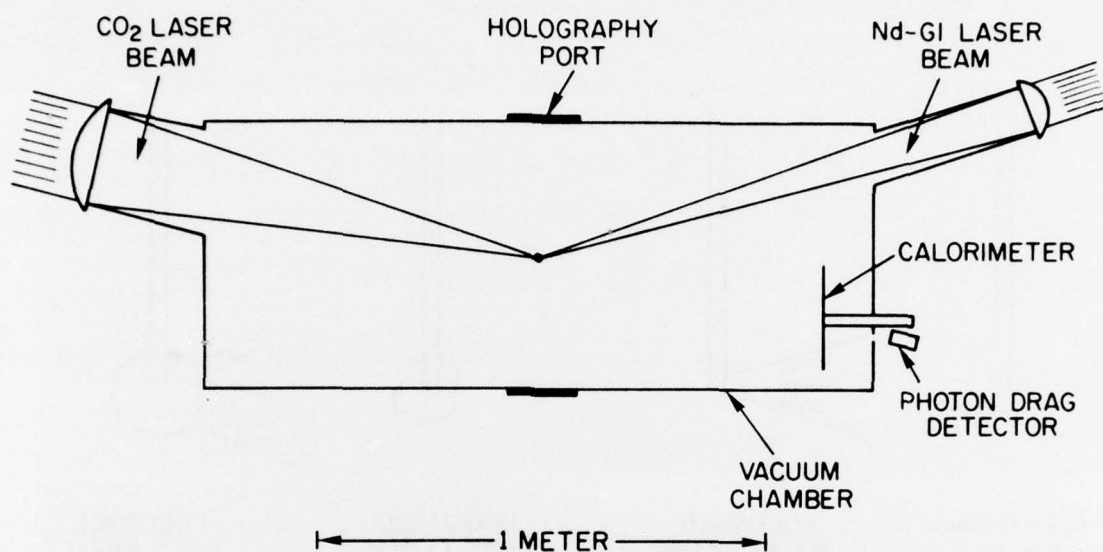


Fig. 2 — Schematic diagram of the top view of the experiment

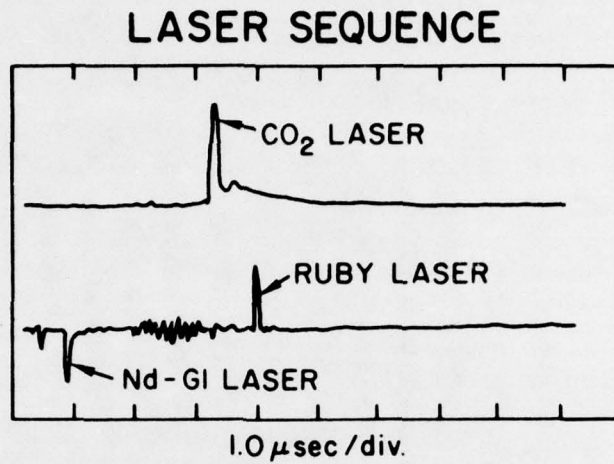


Fig. 3 — Oscillograph recordings of the laser signals showing the time relationships of the Nd/glass, CO<sub>2</sub>, and ruby lasers



Fig. 4 — Interferometric hologram taken 300 nsec after  
the peak of the  $\text{CO}_2$  laser pulse



Fig. 5 — Interferometric hologram taken 1300 nsec after the peak of the  $\text{CO}_2$  laser pulse

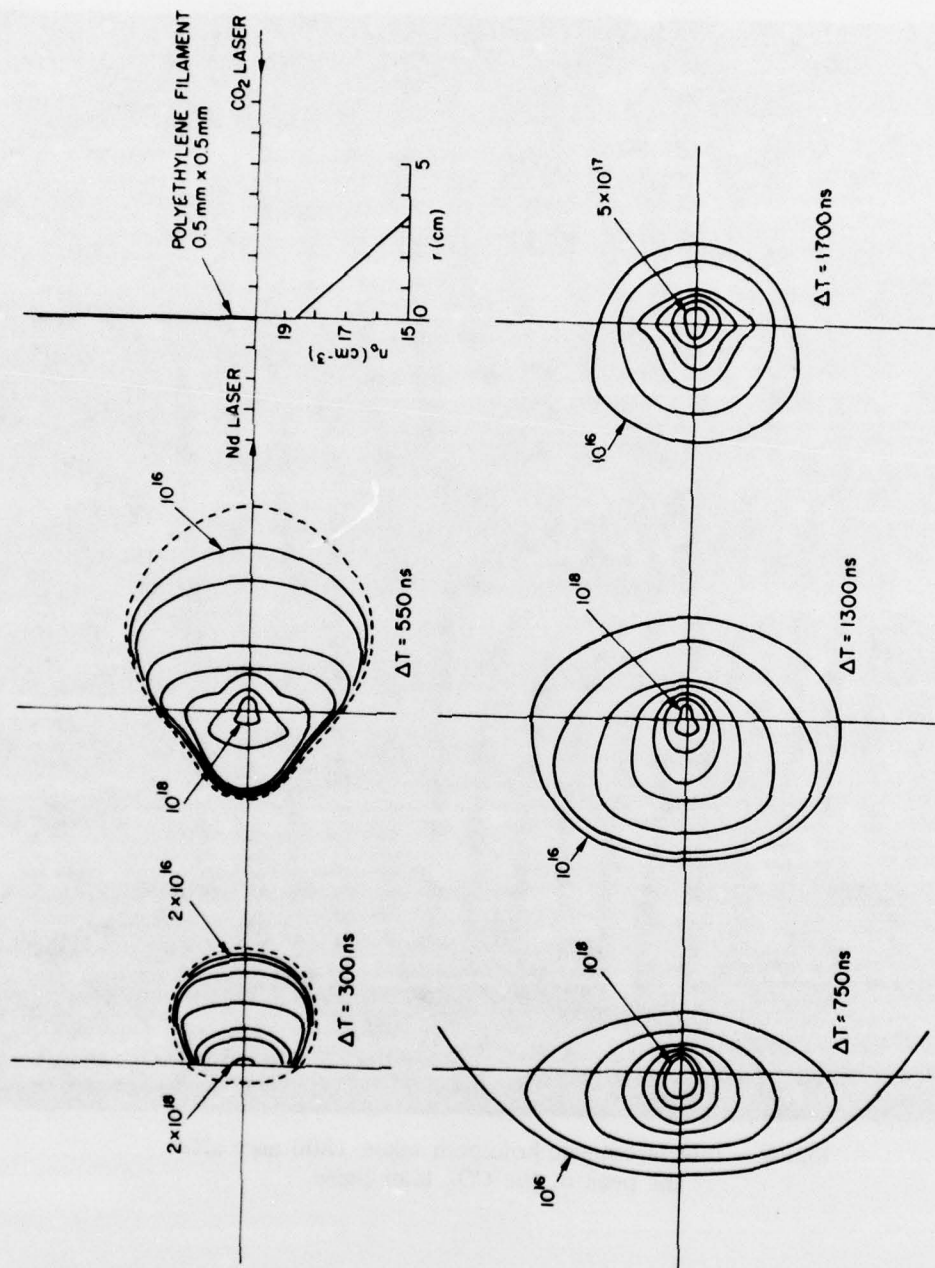


Fig. 6 — Isodensity contours derived from holograms taken at various times after the CO<sub>2</sub> laser peak

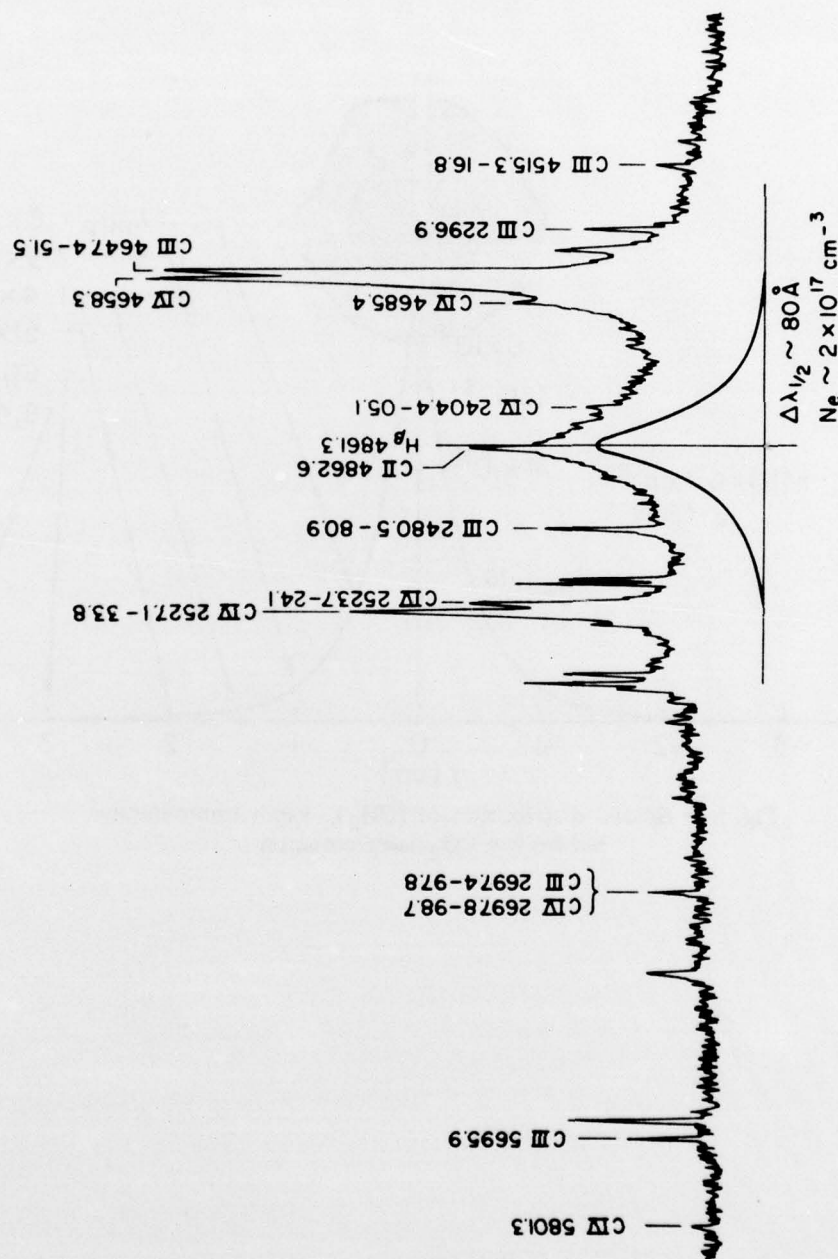


Fig. 7 — Spectral distribution of light emitted by the plasma between 2000 Å and 6000 Å

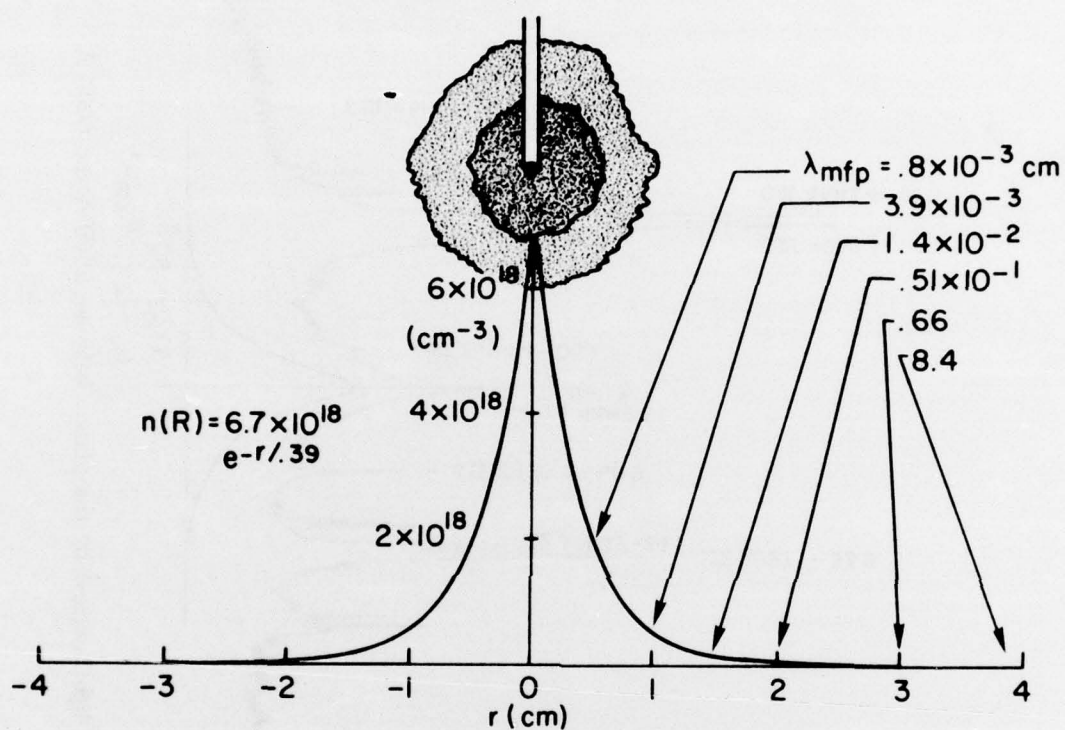


Fig. 8 — Spatial distribution of  $(\text{CH}_2)_n$  vapor immediately before the  $\text{CO}_2$  laser emission

TARGET CONDITION	MEASURED INCIDENT ENERGY	MEASURED TRANSMITTED ENERGY
NO TARGET	646 J	650 J
$(CH_2)_n$ TARGET IN PLACE NO Nd-GI LASER	719 J	638 J
$(CH_2)_n$ TARGET IN PLACE AND VAPORIZED BY Nd-GI LASER	670 J	100 J

Fig. 9 — The result of measurements of the  $CO_2$  laser pulse transmission through the  $(CH_2)_n$  target